UNCLASSIFIED

NOTICES

AD 215621

WADC TECHNICAL REPORT 58-474

AD-215621

THE EFFECT OF TEAM SIZE AND INTERMEMBER COMMUNICATION ON DECISION-MAKING PERFORMANCE

ROBERT G. KINKADE AND J. S. KIDD

LABORATORY OF AVIATION PSYCHOLOGY
THE OHIO STATE UNIVERSITY
AND
THE OSU RESEARCH FOUNDATION

APRIL 1959

CONTRACT No. AF 33(616)-3612

AERO MEDICAL LABORATORY
WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

WADC TECHNICAL REPORT 58-474

THE EFFECT OF TEAM SIZE AND INTERMEMBER COMMUNICATION ON DECISION-MAKING PERFORMANCE

ROBERT G. KINKADE AND J. S. KIDD

LABORATORY OF AVIATION PSYCHOLOGY
THE OHIO STATE UNIVERSITY
AND
THE OSU RESEARCH FOUNDATION

APRIL 1959

CONTRACT NO. AF 33(616)-3612
PROJECT NO. 7184

AERO MEDICAL LABORATORY
WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

McGregor & Werner Midwest Corp., Dayton, O.
44-969 & 970-1100-7-24-59

FOREWORD

This report covers part of the research on man-machine systems being conducted by the Laboratory of Aviation Psychology and the Department of Electrical Engineering of the Ohio State University, with Dr. George E. Briggs as Principal Investigator. The objectives of this research are: (1) the development of new human factors methodology for studying man-machine systems, (2) the application of new methodology to several different types of systems in order to modify and improve the validity and generality of concepts, (3) the development of human factors principles for the analysis and synthesis of systems, and (4) the formulation of human factors principles and information in terms compatible with standard engineering practice.

The present report was prepared for the Engineering Psychology Branch, Aero Medical Laboratory, Directorate of Laboratories, Wright Air Development Center, under Contract No. AF 33(616)-3612, Project 7184, Task 71583, with Dr. James C. McGuire acting as Task Scientist. This work was initiated under Contract No. AF 33(616)-43 with Dr. Ralph W. Queal, Jr. acting as Project Scientist and Dr. Paul M. Fitts as Principal Investigator.

The authors are indebted to several members of the staff of the Laboratory of Aviation Psychology for their continuing interest and help in the planning of the research and the preparation of the manuscript. In particular, we thank Dr. Paul M. Fitts and Dr. George E. Briggs for their substantial contributions.

ABSTRACT

The performance of single individuals, two-man teams without intercommunication, and two-man teams with intercommunication was compared in a complex decision-making task. The task was an operational "game" derived from radar approach control.

Forty-eight students participated. The experimental design utilized a subject x conditions balanced Latin square having six independent replications.

Two-man team performance was superior to that of single individuals, but not proportionately so. Interpretation of the data in terms of productivity per person showed the person working alone to be significantly superior to the person working in a two-man team. Teams with communication were slightly superior to teams having no communication.

The explanation of the results of the individual vs. individuals in a team comparison is hypothesized to lie in the diversion of time and productive capacity in the team situation away from the prime task and into integrative and coordinative behavior.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Walter F. Grether
WALTER F. GRETHER
Director of Operations
Aero Medical Laboratory

TABLE OF CONTENTS

THE EFFECT OF TEAM SIZE AND INTERMEMBER COMMUNICATION ON DECISION-MAKING PERFORMANCE

INTRODUCTION

The common-sense proposition that "two heads are better than one" has been brought into question by a series of recent experimental reports. Taylor and Faust (9) found that the performance of an individual was somewhat reduced when working in a team context on a "twenty questions" task. The same result was observed by Moore and Anderson (6) in a symbolic logic task and by Kidd (3) in both a jumbled-sentence and a jigsaw-puzzle task. The body of evidence accumulated so far is not entirely conclusive, however, and many questions still remain to be answered regarding the effectiveness of two-man teams. Furthermore, there has as yet been little in the way of theoretical explanation for the observed facts.

The present study was designed to serve three interrelated purposes: (a) to compare the performance of single individuals with the performance of two-person teams, (b) to evaluate the contribution of intermember coordinative behavior to team performance, and (c) to validate, insofar as possible, the task situation per se. The task used in the present experiment evolved from experience gained in research on radar air traffic control systems (4, 5, 10).

Most complex tasks can be specified by a set of subfunctions. While such analysis involves the risk of losing part of the dynamic flavor of the total system, compensation occurs in the increased ability to expose specific qualities. As examples, two of the major subfunctions in many complex team efforts are information-processing and decision-making. Of particular interest in the present investigation is the type of decision-making where (a) a later decision is affected by an earlier decision, (b) there is no discernible "right" decision, (c) there are several alternative decisions available at any one time, (d) the situation about which the decisions are made is constantly changing, and (e) there are successive decisions to be made over short periods of time. A task was specifically designed to meet these characteristics while retaining recognizable attributes of the air traffic control context from which it was derived. Thus, the task can be described as a typical operational gaming device (1).

With regard to the three primary experimental goals listed above, the team size variable is straightforward. Coordinative behavior, however, needs explanation. This variable was manipulated through instructions to subjects: In one condition, the two team members were allowed to communicate freely; in the second condition, no such privilege was granted. It was postulated that several consequences might follow this simple manipulation. First, lack of coordination could lead to an increased frequency of gross errors. Second, it is possible that certain aspects of performance would profit by the restriction of coordination by allowing each team member to work on the task undistracted by his partner.

In summary, the questions involved here are as follows: (a) What proportionate advantage in task effectiveness, if any, derives from the use of a two-man

---

Manuscript released by the authors 15 August 1958 for publication as a WADC Technical Report.

team as opposed to a single individual? (b) What is the effect of coordinative behavior in the two-man situation—is it distractive or does it help prevent errors? Note that the first question stresses the proportionate advantage rather than the absolute advantage. For such a purpose, effectiveness must be measured in terms of man-hours or individual output whether the work unit* is a single person or a team.

METHOD

Apparatus and Task

The task employed in this study involved the use of a board and moving tokens, and in some ways resembled board games such as chess or checkers. The board itself is pictured in Fig. 1. Its actual size was 24 in. in diameter and it was covered with a protective sheet of acetate.

The S's task was to move tokens, under specific rules, from the several entry points on the periphery to a goal in the center of the board. There were 32 possible entry points.

The place of entry and the length of each move were determined by a set of coded cards. Cards were presented to S(s) in sequence, a single card for each move. A total of four sets of cards was employed, with eight cards in each set. Each set constituted a balanced program, i.e., the total number of tokens and moves was constant across sets. Table 1 indicates the order of presentation and magnitudes of moves involved in each set. Cards and tokens were color-coded for clarity of assignment.

The S's task was to advance as many tokens from the periphery of the board to the goal in the center as quickly as possible, using the entries and moves indicated on the cards. Since it took more moves than the number indicated on any one card to advance a token all the way from the periphery to the goal, S had several tokens to move during one "turn." Each "turn" involved the following steps: (a) a card from the deck was turned face up by E, (b) S located the assigned entry point and moved the just-entering token through the number of spaces called for on the card, (c) S then moved any tokens already on the board from previous turns in a prescribed order over the prescribed number of spaces. After the entering tokens had been moved, all the other tokens from the same set were moved in succession, beginning with the token which entered first. Since the tokens were numbered consecutively, this meant that the lowest numbered tokens were always moved first. During these moves, S was prohibited from immediately retracing his path, thus "using up" moves. He was also required to maintain a separation of at least one space between the moving token and all other tokens. If he committed a separation error, he was prevented from moving the token further, thereby causing it to remain on that space throughout the problem. These immobilized tokens created a block along the path upon which they were stopped. The S had 30 sec. to finish

* The term "work unit" is used to avoid the ambiguity of a one-man team.

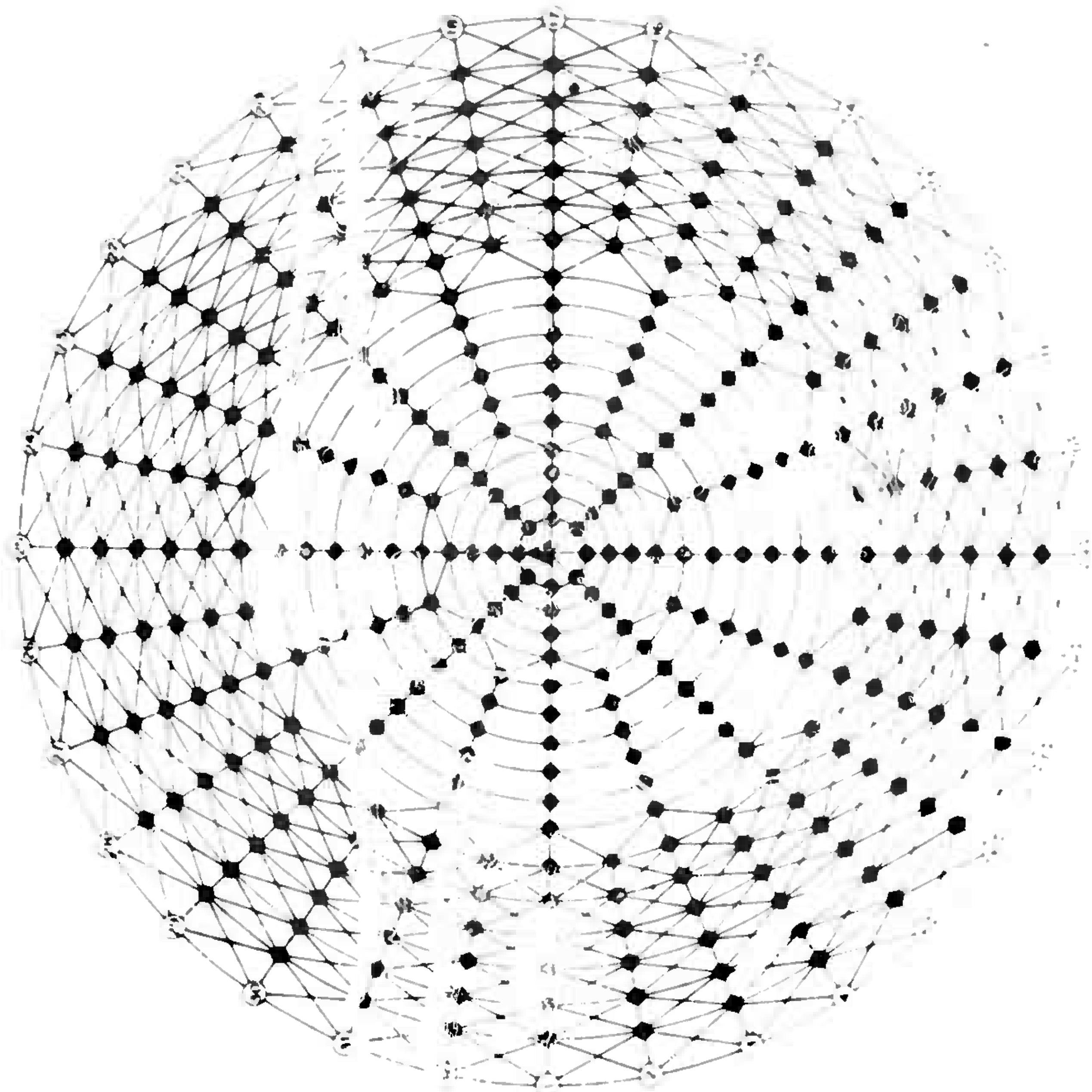

Fig. 1. A redu ed opy of the board. The board was 24 in. in diameter.

moving one token. This re tr ct on was included to insure that S did not decide on a series of moves befor h nade any of them, thereby escaping separation error and the dilemma of blo ki g the path of one token by another.

Table 1

The Entry Position, Number of Moves, and Order of Presentation for Each of the Four Sets of Cards

Set A

No. of Moves	Entry Position
6	26, 28
4	30
6	3, 5
4	7
2	9
2	32
8	None
8	None

Set B

No. of Moves	Entry Position
6	21, 23
2	1
6	27, 29
4	19
2	17
4	31
8	None
8	None

Set C

No. of Moves	Entry Position
6	13, 15
4	20
6	22, 24
4	11
2	16
2	9
8	None
8	None

Set D

No. of Moves	Entry Position
6	14, 16
2	10
6	2, 4
4	12
2	8
4	6
8	None
8	None

Experimental Variables

The basic task was administered under three experimental conditions: (a) individual performance, i.e., a single S, (b) two-man team performance with no communication, and (c) two-man team performance with communication.

a. Individual performance.—Individual performance is defined as follows: Two sets of cards and 16 tokens, half from each of the two sets of tokens, were given to a single S working alone. The S turned over the first card (green in color) of one set, put the green tokens numbered one and two on the appropriate entry numbers, and moved them inward. He then turned over the first card of the remaining set (always colored orange), placed the orange tokens numbered one and two on the appropriate entry numbers, and moved them inward. The S moved the tokens of each set alternately, making the appropriate entries and moving the tokens of one color successively, beginning with the lowest number. When all 16

tokens had been entered and moved the prescribed number of moves, E recorded the criterion measures and the board was cleared.

b. Team performance with no communication.—One set of cards and tokens was given to one S and another to his partner. One S turned over the first card of his set, put the green tokens numbered one and two on the appropriate entry numbers, and moved them inward. The other S then turned over the first card of his set, put the orange tokens numbered one and two on the entry numbers indicated on the card, and moved them inward. The Ss continued to alternate turning over cards, making the indicated entries, and moving all their tokens remaining on the board until all 16 tokens had been entered and moved the prescribed number of moves. The E then recorded the scores and the board was cleared. Two trials were always given to each team.

Under this condition Ss worked together, the decisions of each affecting those of his partner. Moreover, they were instructed to cooperate and were told that the output of the team as a whole was the most important criterion. However, no gestures or verbal communication between partners were permitted.

c. Team performance with communication.—The same procedure was followed as described in (b) above. Each S had a set of cards and tokens, and they alternated in turning over their cards and making the indicated moves. After 16 tokens had entered and moved the prescribed number of moves, E recorded the scores and the board was cleared. This condition differed from (b) in that discussion between Ss was allowed and encouraged.

In all conditions in which two-man teams participated, Ss were instructed to cooperate and were informed that the total team score was the index of performance which was being recorded. Over-all task load was constant for all conditions.. For each of the conditions, 16 tokens per trial or game were advanced an equated number of moves.

Subjects

Forty-eight volunteer Ss from the introductory psychology courses at The Ohio State University participated in the experiment. The Ss were paired arbitrarily to form two-person teams.

Each S participated once in each of the three experimental conditions. For the team conditions, he always had the same partner. The experimental session lasted about 1 hr. and 30 min. None of the Ss had previous experience with the experimental task.

Statistical Design

A treatment × subjects design was used, with counterbalanced order of presentation. All six of the possible orders of presentation of the three conditions were used. The six orders were replicated four times, with a total of 24 pairs of Ss participating in each of the three conditions.

Criterion Scores

Three criterion measures were recorded: (a) time scores, the time required to finish a problem; (b) output scores, the number of tokens which Ss moved through the goal per minute; and (c) error scores, the number of separation errors per problem.

RESULTS

Work Unit Productivity

The first step in the evaluation is a comparison of the total proficiency of the unit as a whole under the various conditions. Thus, the combined output of two people working together is compared to the output of a single person. Because the time scores were skewed, the experimental conditions were evaluated by the Friedman two-way analysis of ranks test, χ^2_r (8). The χ^2_r was statistically significant ($P < .02$). When Ss worked together, the problems were completed in less time than when Ss worked independently. The time scores were lower when Ss were allowed to communicate with each other than when they could not discuss moves or strategy (see Table 2).

The output scores (pieces through the goal per minute) were evaluated by the F test; however, they were not statistically significant ($P < .50$). These scores were lower when Ss worked together without communication than when they worked under either of the other conditions (see Table 2).

The χ^2_r used to evaluate the error scores (number of separation errors per problem was not statistically significant ($P < .20$). More separation errors were made in the condition where Ss worked together without communication than in either of the other conditions. The lowest error score was obtained when Ss worked together with communication (see Table 2).

Table 2

Summary of Unit Productivity

Performance Criteria	Experimental Condition: Single Individual	Two-man Team without Communication	Two-man Team with Communication	Statistical Test	P
Mean time to complete problem (in min.)	26.43	24.45	24.38	χ^2_r	.02
Mean number of pieces through goal per minute	.751	.732	.829	F	NS
Mean separation errors per problem	4.58	4.71	4.29	χ^2_r	NS

Proportionate Productivity

In addition to evaluating the effects of the conditions on unit performance, the effects were evaluated in terms of individual efficiency. That is, the rate of output per individual was calculated in the following manner: The output scores obtained when Ss worked together were divided by two. The resulting score represented the output score per individual under the conditions tested. The averages obtained by a reanalysis of the output scores are presented in Table 3. Since in this instance, the scores obtained were approximately normal in distribution, the effects of the conditions were evaluated by the F test. The evaluation, as summarized in Table 4, indicates that the observed trend of greater output by the single individual is significant beyond the .01 level of confidence. Table 5 contains a condition-by-condition breakdown evaluated by the t test. The point at issue that is clarified by this latter comparison is whether or not the communications variable per se is effective. Here, it is found that the significance obtained in the F test is almost exclusively a product of the individual vs. two-man team comparison and that the presence or absence of open communication between partners does not have a profound effect in this situation.

Table 3

Summary of Individual Productivity

Performance Criteria	Experimental Condition: Single Individual	Two-man Team without Communication	Two-man Team with Communication	Statistical Test	P
Number of pieces through goal per min. per person	.751	.366	.415	F	$<.01$

Table 4

Analysis of Variance for Output Rate per Subject

Source	df	Mean Square	F
Treatments	2	1.056	31.06*
Subjects	23	.033	---
Orders	5	.027	---
Residual	41	.034	
Total	71		

* P $<.01$

Table 5

Comparison of Pairs of Experimental Conditions by t Test (Number of Pieces Through Goal Per Minute Per Person as Criterion)

Conditions Compared	t	P
Independent vs. team with no communications	7.00	$<.01$
Independent vs. team with communications	5.82	$<.01$
Team with no communications vs. team with communications	1.26	NS

DISCUSSION

The implications of the present study derive largely from the use of a dual analytic procedure: first, comparing effectiveness on a unit basis and, second, comparing effectiveness on an individual basis. It is clear from the first step that some benefits derive from a team effort, particularly when communication between team partners is open. While not statistically significant, the differences between conditions on the "separation errors" criterion is most provocative. Here is some evidence to the effect that cross-monitoring of output does lead to a reduction in error frequency; a mechanism proposed as far back as 1932 (7) to account for group problem-solving superiority.

The rather weak group advantage in performance reflected in the output criterion suggests that while the group may be more productive than the individual worker, it is not proportionately so (e.g., two men working as a team are not twice as productive as a single individual working on the same task). Such an observation is verified when the second analytic step is taken. In the present task, when the comparison is made on an individual vs. individual basis (e.g., performance divided by number of team members), the person working alone has a superior output. This finding verifies results of previous investigations by Taylor and Faust (9), Moore and Anderson (6), and Kidd (3).

The question remains: Why does not the effectiveness of the unit increase proportionately as members are added? The answer appears to lie in the changed nature of the task. Working by himself, the individual has to devote his attention only to the objective characteristics of the task. Adding another person, however, requires that some kind of coordination take place (even when communication is not allowed). The operator, under such circumstances, must share his available time between the direct demands of the task and the demands of coordinating with his partner.

With regard to overt cooperation as manipulated through communication accessibility, the trend, while not statistically significant, favored free communications. A recent report by Versace (10) bears on this issue. He found, in a more dynamic yet somewhat more stereotyped version of the task used here,* that there was no appreciable change in the performance of a two-man radar air traffic control team when communications accessibility was manipulated. His conclusion that the task requirements are major determinants of the efficacy of coordination behavior seems consistent with observations made in the present study. The degree of overlapping function was somewhat higher in the present case and a somewhat greater contribution of communication accessibility to team performance was observed.

In summary, increasing the number of workers in the context of a complex task does not result in a proportional increment in performance. Allowing open communication in cases where there is some functional overlap helps the system to a small degree.

Derivative issues pointed out by the present study which require further investigation are (a) the precise relationship between degree of functional overlap and the usefulness of member coordination, (b) the contribution of team membership to motivation and willingness to remain in the task environment as opposed to performance per se, and (c) the nature of cross-monitoring and subsequent error frequency in a team situation.

The over-all agreement of the findings derived from the present study with those obtained from a different task environment (10), suggests that the operational game provides a useful context for the conduct of team research.

SUMMARY

The performance of single individuals, two-man teams without intercommunication, and two-man teams with intercommunication was compared in a complex decision-making task. The task was an operational game derived from radar air traffic control.

Forty-eight students participated. The experimental design utilized a subjects X conditions balanced Latin square having six independent replications.

Two-man team performance was superior to that of single individuals, but not proportionately so. Interpretation of the data in terms of productivity per person showed the person working alone to be significantly superior to the person working in a two-man team. Teams with communication were slightly superior to teams having no intercommunication.

The explanation of the results is hypothesized to lie in the diversion of time and productive capacity in the team situation away from the prime task and into integrative and coordinative behavior.

---

* Versace utilized the OSU thirty-target electronic air traffic control simulator (2) and employed an in-line control procedure. The present study employed an analog of parallel control procedures.

REFERENCES

1. Cushen, W. E. "Operational Gaming in Industry." In J. F. McCloskey and J. M. Coppinger, Operations Research for Management. Johns Hopkins Press, Baltimore, Maryland, 1956.

2. Hixson, W. C., Hartor, O. A., Warren, C. E., and Cowan, J. D., Jr. An Electronic Radar Target Simulator for Air Traffic Control Studies. WADC Technical Report 54-569. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-43 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, December 1954.

3. Kidd, J. S. "Social Influence Phenomena in a Task-Oriented Group Situation." Journal of Abnormal and Social Psychology. Vol. 56. January 1958. pp. 13-17.

4. Kidd, J. S., and Kinkade, R. G. Air Traffic Control System Effectiveness as a Function of the Division of Responsibility between Pilots and Ground Controllers: A Study in Human Engineering Aspects of Radar Air Traffic Control. WADC Technical Report 58-113. Report of the Laboratory of Aviation Psychology Laboratory under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, June 1958.

5. Kidd, J. S., Shelly, M. W., Jeantheau, G., and Fitts, P. M. The Effect of Enroute Flow Control on Terminal System Performance: A Study in Human Engineering Aspects of Radar Air Traffic Control. WADC Technical Report 57-663. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, December 1957.

6. Moore, O. K., and Anderson, S. B. "Search Behavior in Individual and Group Problem Solving." American Sociology Review. Vol. 19. October 1954.

7. Shaw, M. E. "Comparison of Individuals and Small Groups in the Rational Solution of Complex Problems." American Journal of Psychology. Vol. 44. 1932. pp. 491-504.

8. Siegel, S. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill Book Company, Inc., New York, N. Y., 1956.

9. Taylor, D. W., and Faust, W. L. "Twenty Questions: Efficiency in Problem Solving as a Function of Size of the Group." Journal of Experimental Psychology. Vol. 44. May 1952. pp. 360-368.

10. Versace, J. The Effect of Emergencies and Communications Availability with Differing Entry Rates: A Study in Human Engineering Aspects of Radar Air Traffic Control. WADC Technical Report 56-70. Report of the Laboratory of Aviation Psychology under Contract No. AF 33(616)-3612 between The Ohio State University Research Foundation and Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, December 1956.